Clouds and Climate

Introduction

Clouds are major regulators of the radiative heating of the Earth. They have two major (and offsetting) effects.

- Increase the Earth's albedo thus lowering the amount of shortwave radiation absorbed by the Earth. This results in cooling of the earth.
- Absorb Longwave radiation thus reducing the longwave loss to space. This results in warming of the earth

How these two effects very with time and space (geography that is) and the effect of cloud type and structure is not well understood. The effect of clouds on the radiative balance of the earth is a large uncertainty in several areas.

- The prediction of climate changes associated with anthropogenic increases in trace gases
- Understanding past and future climate changes caused by variations in the solar constant or the orbital parameters of the earth.

ERBE

Satellites

To study cloud dynamics, in the 1980's NASA initiated the ERBE program (Earth Radiation Budget Experiment). Three satellites were in the ERBE program. The first was the ERBS – I think you can figure out this acronym. The other 2 ERBE instruments were put aboard two NOAA satellites NOAA-9 and NOAA-10.

Cloud Forcing Concept

Consider a domain (spatial area) large enough to contain both overcast and clear skies. In overcast regions, water vapor occurs along with condensed water and/or ice. In clear regions, water occurs on as a vapor. In such a domain (meteorologically-speaking a cloudy region), the net radiative heating for the surface-atmosphere column is:

$$H = S(1 - a) - F$$

Where S is the solar irradiance, α is the albedo and F is the longwave flux emitted to space. To describe the effect of clouds we can define a cloud forcing (C).

$$C = H - H_{clr}$$

Thus clouds should cause any difference between the net radiative heating averaged over the domain and the heating averaged over only clear portions of the domain. C can be rewritten as:

$$C = C_{sw} + C_{lw}$$

Where $C_{sw}=S(\alpha_{cl}-\alpha)$ and $C_{lw}=F_{clr}-F$.

C_{sw} gives a quantitative estimate of the increased reflectivity of clouds over clear sky (well, perhaps with the exception of snow).

When clouds are present less energy is lost to space in the longwave and C_{lw} is a measure of this effect. The net effect of clouds is thus simply $C_{sw}-C_{lw}$.

The above equations can also be considered slightly differently in a manner that allows us to consider the effect of the fraction of each clouds in the domain. If we divide the full domain into *i* number of subregions, then $C_{sw}=S(\alpha_{clr}-\alpha)$ is equal to:

$$S(a_{clr} - a) = S\sum_{i} f_i \left(a_{clr,i} - a_{o,i}\right)$$

Where f_i is the cloud fraction and $\alpha_{o,i}$ is the overcast albedo for the *i*th region. However, it is much easier to obtain the forcing using the left-hand side of the equation because clear-sky fluxes are more homogenous which minimzies errors caused by poor sampling. Also it is not necessary to determine hard to measure quantities like cloud fraction.

Clear Sky albedo and LW flux

Albedo
- Oceans are the darkest regions of the globe
- Ocean albedo increases toward poles because of increasing ocean albedo as sun gets lower in the sky
- Snow-covered surfaces are the brightest, followed by the major deserts.
- Rainforests are the darkest land surface covers

LW Flux
- Highest at the equator and drops off toward poles

Long- and Short-wave cloud forcing

Longwave

- In general clouds reduce the LW emission to space.
- Peak values occur over tropical regions and decrease towards the poles
- This reduction in emission is largely the result of the emission from cold-cloud tops, optically thick high clouds reduce the emission more than low clouds. Hence maximum forcings occur in areas of extensive cirrus cloud decks.

Shortwave

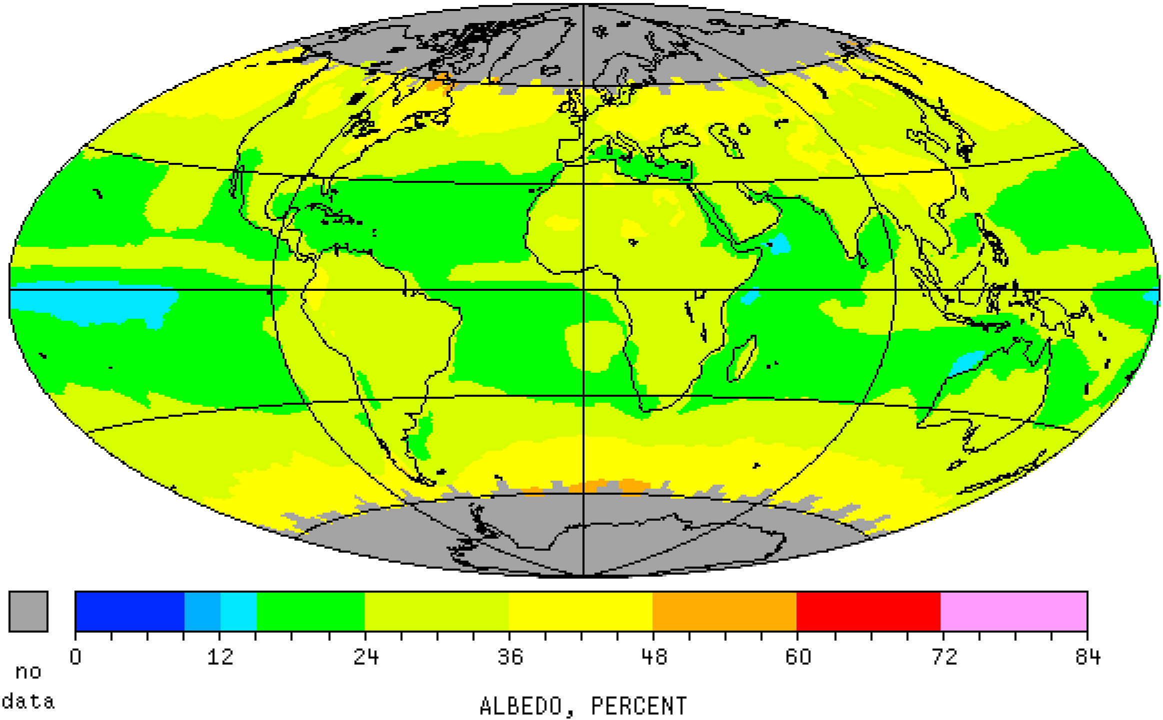
- Peaks in the mid-latitudes
- Peaks over tropical convective regions

Read article to understand the effect of clouds on the shortwave/longwave and net forcings

ALBEDO

ERBS, 2.5 DEG SCANNER, MEAN OF 1989

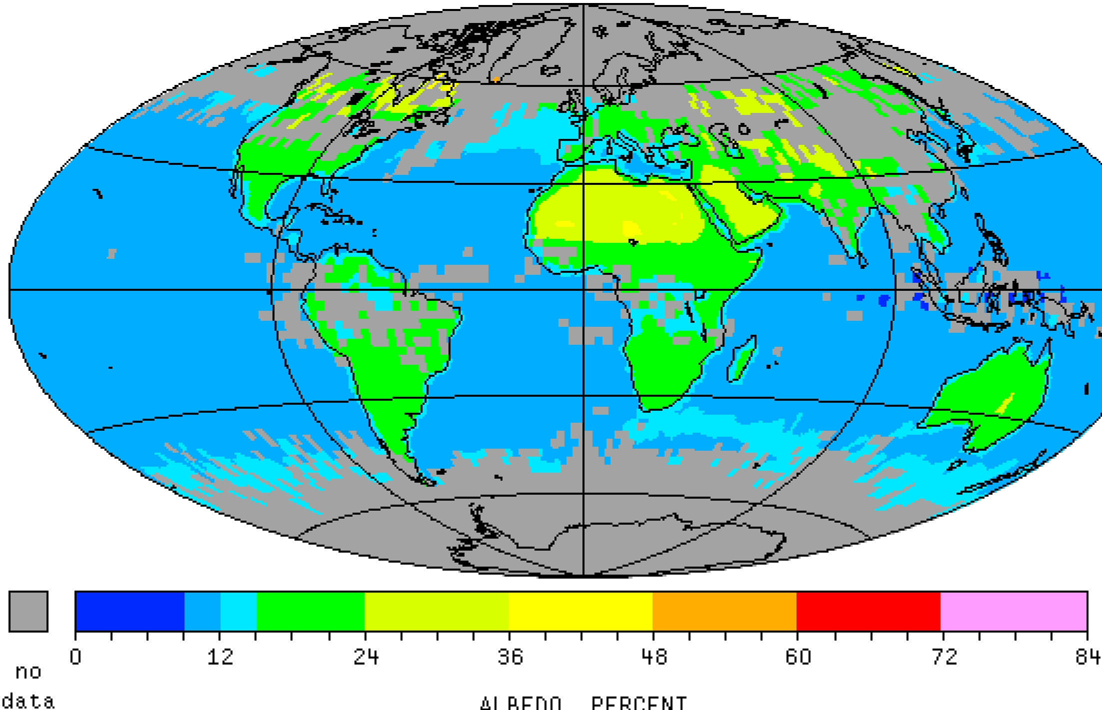
GLOBAL MEAN: (60S-60N = 26.8) %

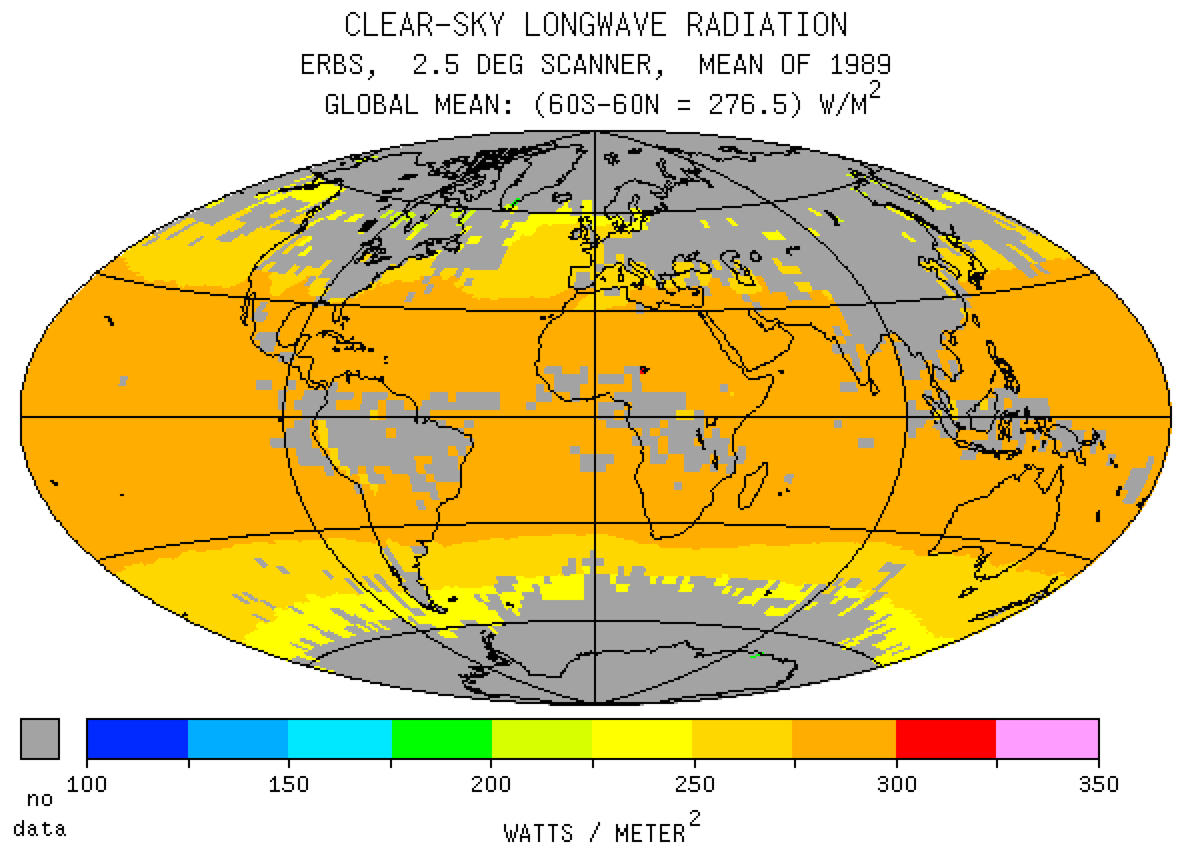


CLEAR-SKY ALBEDO

ERBS, 2.5 DEG SCANNER, MEAN OF 1989

GLOBAL MEAN: (60S-60N = 13.4) %

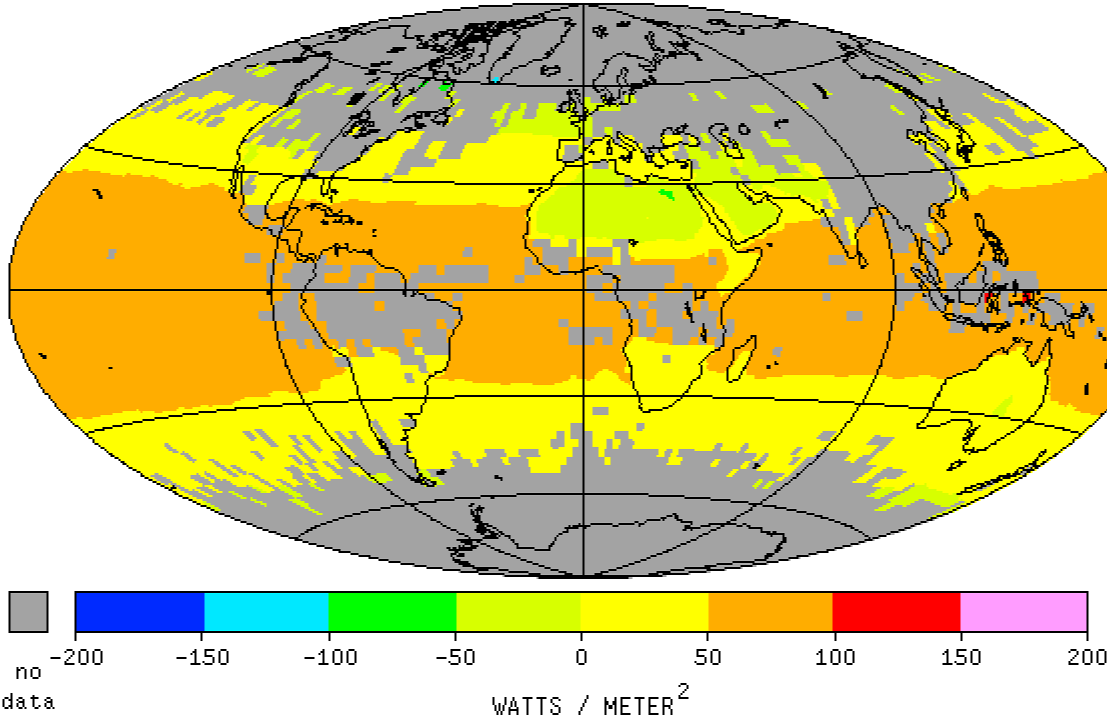



CLEAR-SKY LONGWAVE RADIATION
ERBS, 2.5 DEG SCANNER, MEAN OF 1989
GLOBAL MEAN: (60S-60N = 276.5) W/M2
no data
100
150
200
250
300
350
WATTS / METER2

CLEAR-SKY NET RADIATION

ERBS, 2.5 DEG SCANNER, MEAN OF 1989

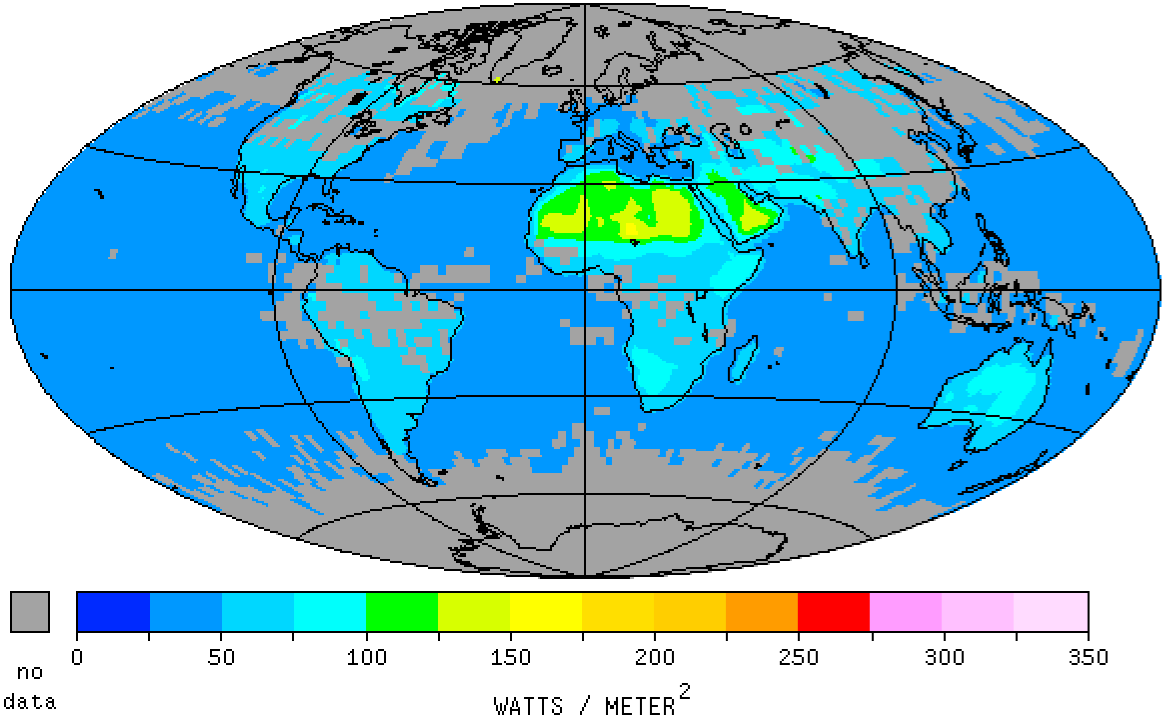
GLOBAL MEAN: (60S-60N = 39.5) W/M^2

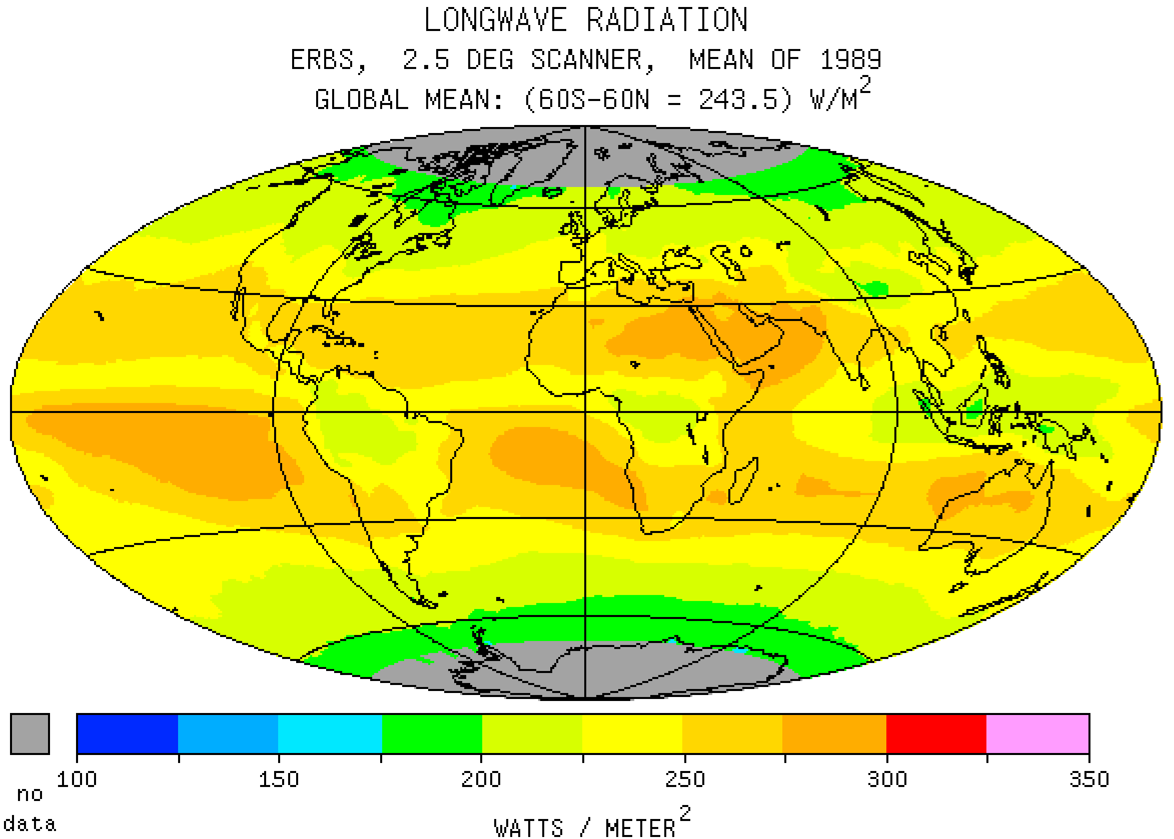


CLEAR-SKY SHORTWAVE RADIATION

ERBS, 2.5 DEG SCANNER, MEAN OF 1989

GLOBAL MEAN: (60S-60N = 49.7) W/M^2

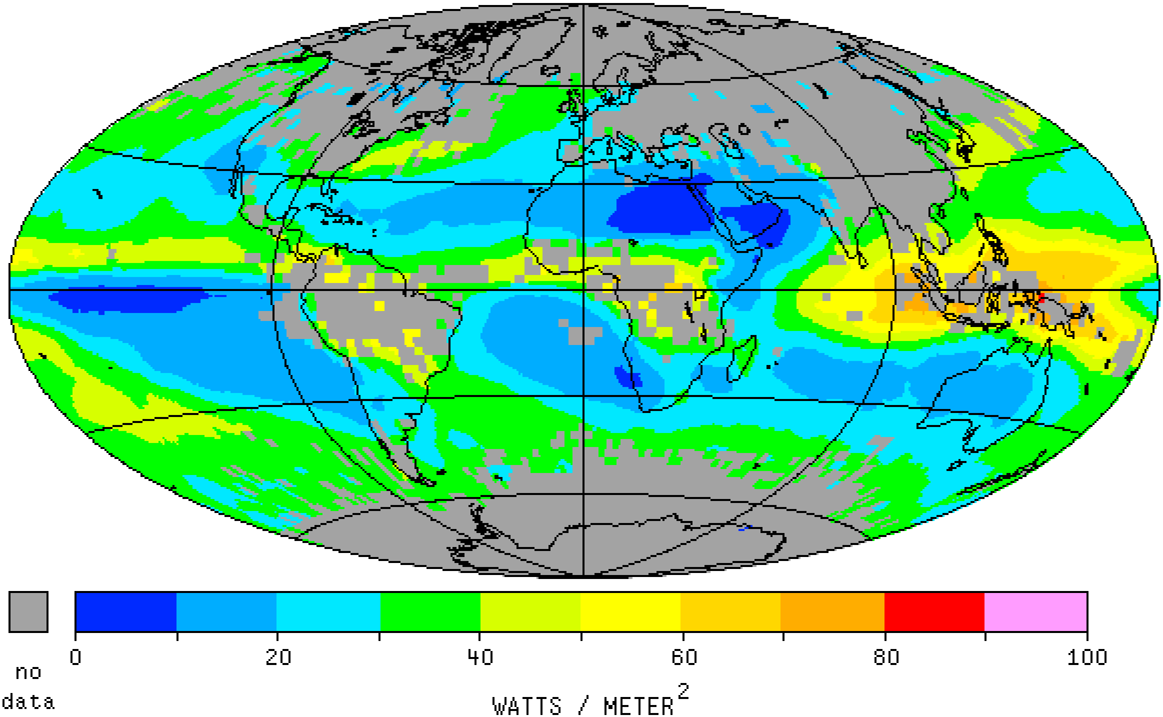


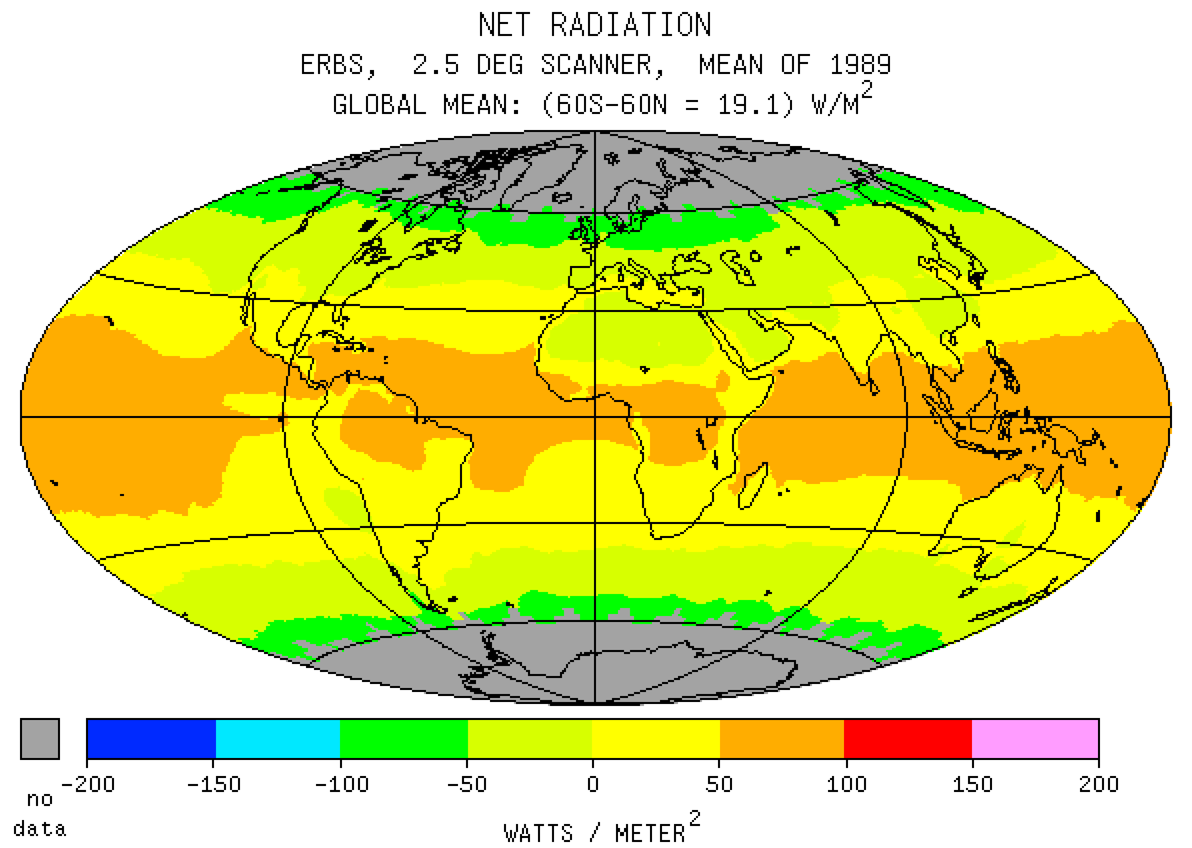

LONGWAVE RADIATION
ERBS, 2.5 DEG SCANNER, MEAN OF 1989
GLOBAL MEAN: (60S-60N = 243.5) W/M2
no data
100
150
200
250
300
350
WATTS / METER2

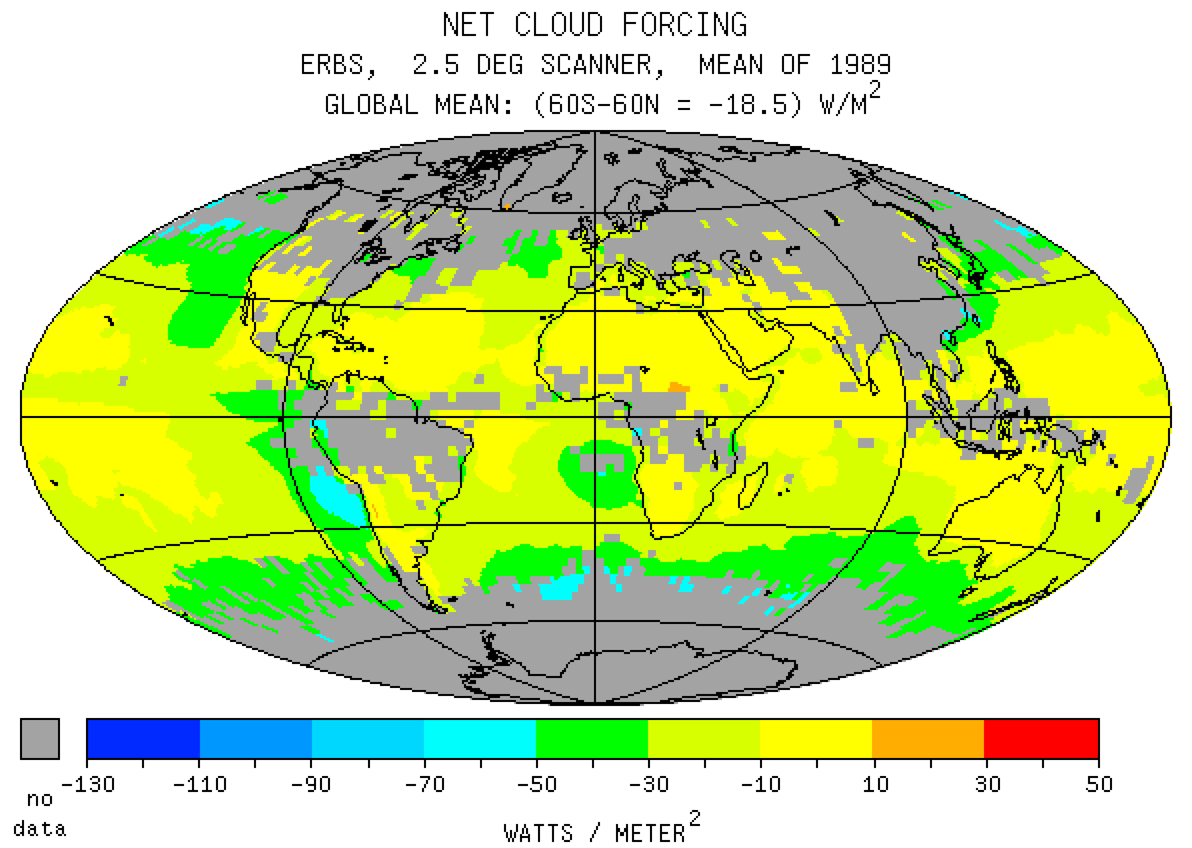
LONGWAVE CLOUD FORCING

ERBS, 2.5 DEG SCANNER, MEAN OF 1989

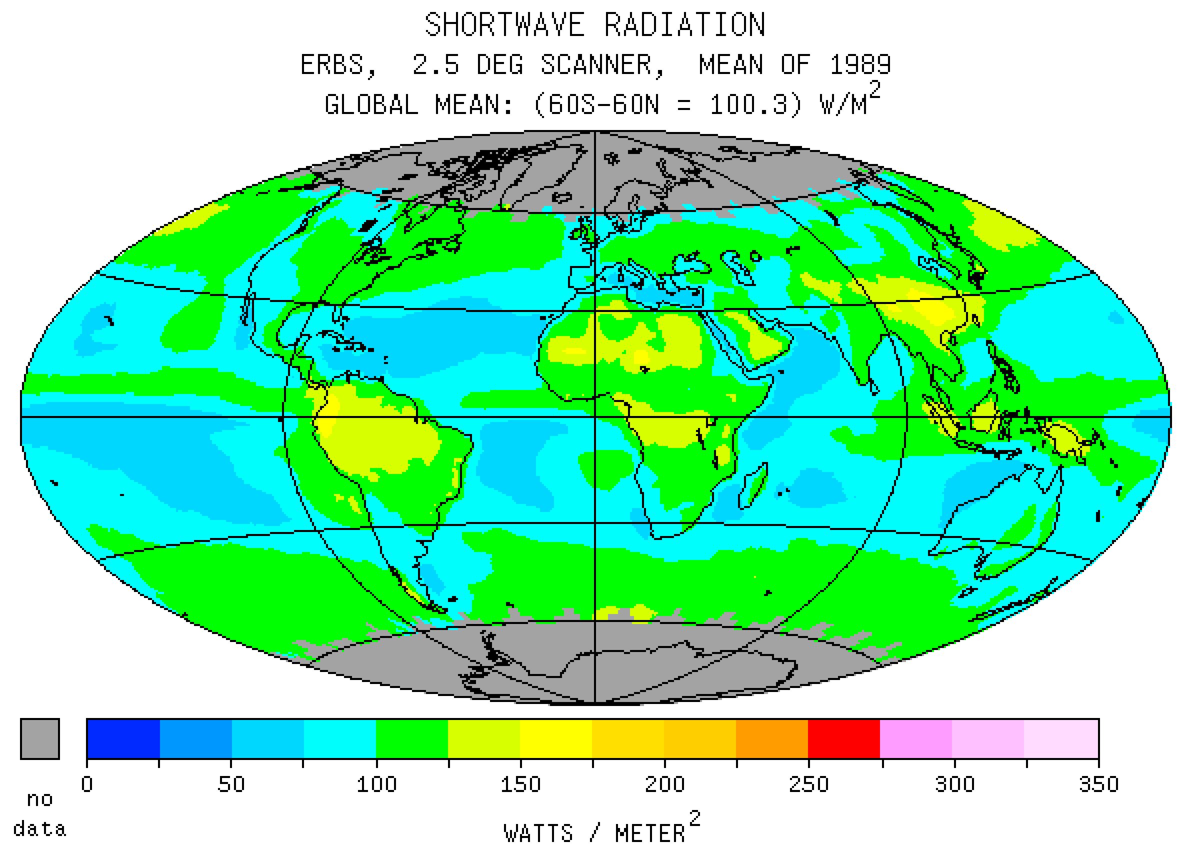
GLOBAL MEAN: (60S-60N = 30.3) W/M^2



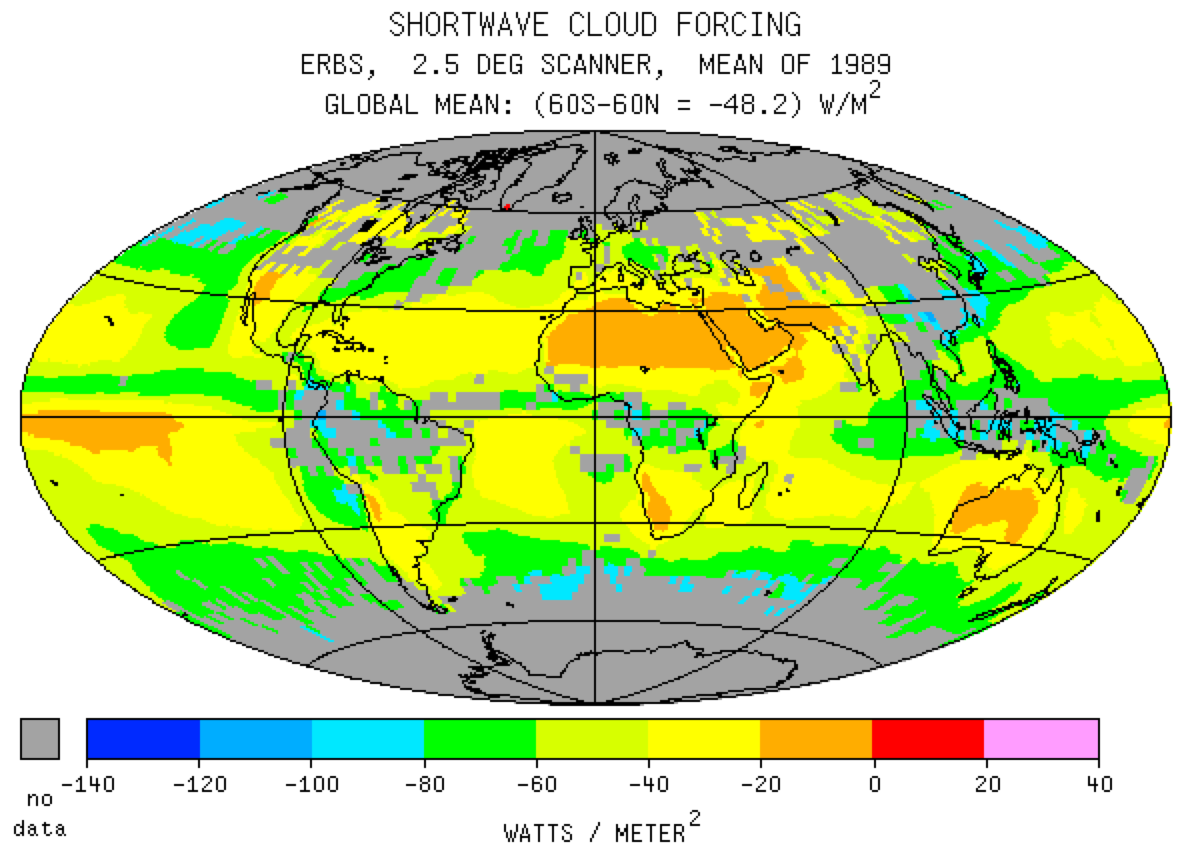

NET RADIATION
ERBS, 2.5 DEG SCANNER, MEAN OF 1989
GLOBAL MEAN: (60S-60N = 19.1) W/M2
no data
-200
-150
-100
-50
0
50
100
150
200
WATTS / METER2



NET CLOUD FORCING
ERBS, 2.5 DEG SCANNER, MEAN OF 1989
GLOBAL MEAN: (60S-60N = -18.5) W/M2
no data
-130
-110
-90
-70
-50
-30
-10
10
30
50
WATTS / METER2



SHORTWAVE RADIATION
ERBS, 2.5 DEG SCANNER, MEAN OF 1989
GLOBAL MEAN: (60S-60N = 100.3) W/M^2
no data
0
50
100
150
200
250
300
350
WATTS / METER^2


SHORTWAVE CLOUD FORCING
ERBS, 2.5 DEG SCANNER, MEAN OF 1989
GLOBAL MEAN: (60S-60N = -48.2) W/M^2
no data
-140
-120
-100
-80
-60
-40
-20
0
20
40
WATTS / METER^2